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Effect of Process Techniques on Three Feedstocks Mix on Briquette Performance Properties

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Abstract: Energy availability at domestic level is a challenge across the world and especially in Africa. Firewood is the major source of energy for cooking for households in Kenya and there is need for a friendly sustainable environmental fuel. Carbonized biomass materials (briquettes) are considered a substitute. This study thus evaluated effect of selected briquetting techniques on briquettes' performance properties. Milled charcoal dusts mixed in a ratio of 1:1:1 (Rice husk, maize cob, and sugarcane bagasse) with molasses binder in the ratio of 6:1 was hence ready for densification and agglomeration. The Water Boiling Test was used in determination of the briquette's performance characteristics for various parameters. High (screw press); and low (drum agglomerator and hand making) pressure briquetting techniques were distinctly different in ignition time (minutes), time to boil (minutes) burning rate (g/min), specific fuel consumption (g/ml) and power output (kW) values as (4, 3, 3; 14, 12, 11: 0.8, 1.1, 1.3; 0.11, 0.13, 0.15; and 1.8, 1.4, 0.75). Diversified briquetting techniques, number and type of feedstocks are thus factors that influence performance characteristics of briquettes in converting the agricultural and or other wastes for useful energy application. This knowledge should enable users to make choices on techniques for optimum efficiency towards realization of Sustainable Development Goal Number #7 on affordable and clean energy.

Keywords: Energy, Feedstock, Carbonization, Technique, Briquettes, Performance Properties

1. Introduction

Energy is one of the components of sustained development and poverty eradication for basic human needs and it is both vital and key for social economic growth [24]. Its availability at domestic level is a challenge across the world and especially in Africa where deforestation and high cost of Liquid Petroleum Gas (LPG) or cooking gas, electricity, and kerosene is experienced [9, 42, 40]. In developing countries demand for charcoal is expected to rise [33] due to urbanization rate. Fossil fuels all over the world though is limited, demand for developed industries' energy consumption has extremely increased [19]. As ecological issues demand priority for conserved natural resources, high usage of these limited available fossil fuels has led to undesirable outcomes [19]. Thus, to avoid dependence on fossil fuel, waste biomass has been considered as a substitute fuel source.

Significant quantities of biomass are available in Sub-Saharan Africa for conversation into domestic energy sources [3, 4]. Biomassare however underutilized due to poor combustion characteristics [10]. Handling, utilizing, transporting, and storing biomass in original form is also not easy [30, 31]. According to da Silva et al. [11] it has been reported that biomass in its original form has high moisture content, low bulky density, irregular shapes and sizes. To improve on handling and reliability of biomass energy, densification should then be undertaken [23]. Kenya is one country that would greatly benefit from densification of biomass, especially for the peri and urban areas.

Wilaipon, P. [47] classified briquetting technology as high or low-pressure compaction, (low (5MPa), intermediate (5-100MPa) and high (100MPa and above). On classified techniques the equipment used are either piston or screw press [15]. Abdulkareem et al. [1] notes that briquettes produced from these processes have a density range between 900-1300 kgm^{-3}. Most studies identified such machines as either mechanical, hydraulic or manual and often are screw press extruders, roller press or piston press [45]. Non-pressurized techniques (drum agglomerator) though require binder to aid in agglomeration, have a density range of less than 900 kgm^{-3} [20].

Briquetting using these techniques have been extensively done [20; 34; 45] and it's noted the properties are affected by the type and combination of feedstocks. Song, B. [41] and Tumuluru, J. S. [44] also noted that durability and mechanical strength of the briquettes can be improved by blending with another biomass material.

Rice husks, corncobs and sugarcane bagasse were hence used as feedstocks in this study. These agricultural wastes are usually left to rot in the farm or burnt thus releasing smoke to the atmosphere that may have effect on the ozone layer. These wastes can be recovered and converted into a clean and usable fuel (briquettes). In this study, carbonization of the feedstocks was undertaken in a drum kiln with densification of a screw press, drum agglomerator and hand briquetting. This was to determine the effect of process techniques on three feedstocks mix on briquette performance properties.

2. Materials and Methods

The study was done at the Faculty of Engineering and Technology, Department of Agricultural Engineering at the Energy Laboratory; Egerton University, Njoro, Nakuru County (Latitude 0°22'30.0" S Longitude 35°55'30.0" E). Laboratory tests for analysis of briquettes was carried out at Egerton University's Food Science and Chemistry Departments.

2.1. Screw Press and Drum Agglomerator

The screw press was fitted with a 5 horse power single phase motor and an 800mm length auger shaft with a diameter of 38.8mm. Extruder pipe was 38 mm diameter which was smaller than auger shaft for increase of pressure. The drum agglomerator had a 3 horse power single phase motor that rotated a wheel that in turn rotated the drum. The drum further had a scrapper that aided in the process of granulation. The fabrication of screw press and drum agglomerator was adopted and modified from the existing techniques at Egerton University.

2.2. The Sample

The rice husks, sugarcane bagasse and corncobs were obtained from Western Kenya Rice Mills (WKRM) in Ahero Town Kibos sugar factory and from Egerton Ngongongeri farm respectively. These were respectively sun dried to moisture contents of about 12-14% [5], 10-14% (Kenya Briquettes Manufacturers Authority, KBMA) and 8-12% [5]. Each of the feedstocks were carbonized in a drum kiln. The fireplace of the kiln was set, the vents opened (intake and exhaust) for enough oxygen that was for about 30 minutes. This was then closed for at least 2 hours in absence of oxygen for carbonization and the temperature monitored by a thermometer mounted on the kiln. The process output was biochar of each feedstock which size was reduced to < 2mm by a hammer mill for ease of densification. Biochar (s) was then mixed at 1:1:1 ratio in readiness for briquetting.

2.3. Briquettes Production

Five kilograms (5kg) of each blended biochar of the carbonized feedstock were weighed and binder sprinkled beforehand-feeding into the screw press for briquette moldings. In the case of rotating drum agglomerator, blended biochar was poured on the drum and binding agent sprinkled to the mixture in the ratio of 6:1 (blend to binder) as the drum rotated until the granules grew, approach used by [17]. Once formed, the spherical briquettes were removed. Also, briquettes were produced by hand by taking fifty (50) grams of each carbonized material, weighed and mixed with binder in the ratio 6:1. The briquettes were then allowed to sun dry for three days to reduce moisture content to almost 8% w.b in line with the recommendations by [35] and KBMA. The briquettes from each technique were sampled for Water Boiling Test to determine their performance characteristics.

2.4. Performance of Briquettes

The performance of the resulting briquettes was assessed by the Water Boiling Test (WBT version 4.2.3) with an improved "jiko" (cooking stove called "Jiko Okoa"). The local boiling point was determined using equation 2.1 as used by [8].

$$Tb = \left[100 - {}^{h}/_{300}\right]^{\circ}C \quad (1)$$

Where; Tb – Local boiling point.

h – Altitude in meters.

During the assessment, high power phase was determined according to [26] recommendation. Further assessment on performance of the briquettes was conducted considering Simmering-Lower power phase according to [7]. Results are presented in Table 1 in results section.

Methods used by [16, 36] to determine performance characteristics of the briquettes were adopted for this study (including specific fuel consumption, power output, burning rate, burning time and ignition time). The equations used were as in 2.2-2.5;

$$Specific\ Fuel\ Consumption = \frac{mass\ of\ fuel\ burnt\ (kg)}{mass\ of\ boiled\ water\ in\ the\ pot\ (kg)} \quad (2)$$

$$Power\ Output\ (Kj/\text{sec}) = \frac{mass\ of\ fuel\ burnt\ (kg) x\ calorific\ value\ of\ the\ fuel\ (Kj/Kg)}{time\ taken\ to\ burn\ fuel\ (\text{sec})} \quad (3)$$

$$Burning\ Rate\ (Kg/\text{sec}) = \frac{mass\ of\ the\ fuel\ burnt\ (kg)}{time\ taken\ to\ burn\ the\ fuel\ (sec)} \quad (4)$$

$$Ignition\ Time\ (\text{min}) = T_1 - T_0 \quad (5)$$

where; T_1 – time that the briquette is ignited.
T_o – time briquette was lighted.

2.5. Data Analysis

Data obtained from the experiment was subjected to statistical analysis software (SAS). Analysis of Variance (ANOVA) was used at 5% level of significance. The degrees of freedom, sums of square, and mean sum of squares were calculated and then the levels of significance difference between the factors were determined using the F-test.

3. Results and Discussion

3.1. Performance Properties of Briquettes

The performance values of briquettes from three techniques were tabulated and recorded as in Table 1. The performance properties were affected by type of the technique (low vs high pressure).

Table 1. *Effect of Technique on Briquettes' Performance Parameters.*

Technique	PARAMETERS														
	IT (min)			TB (min)			BR (g/min)			SFC (g/ml)			PO (kW)		
	CS	HS	Av	CS	HS	Av	CS	HS	Av	CS	HS	Av	CS	HS	Av
Screw Press	4	4	4	16	12	14	0.7	0.9	0.8	0.14	0.08	0.11	1.3	2.3	1.8
Drum Agglomerator	3	3	3	13	11	12	0.9	1.3	1.1	0.15	0.11	0.13	0.8	2.0	1.4
Hand briquetting	3	3	3	12	10	11	1.0	1.6	1.3	0.17	0.13	0.15	0.5	1.0	0.75

IT=ignition time, TB=time to boil, BR=burning rate, SFC=specific fuel consumption, PO=power output, CS=cold start, HS=hot start, AV=average.

3.1.1. Ignition Time

Ignition time was taken as the average time taken to light a known mass of fuel in line with Onuegbu et al. [36]. The longest ignition time of 4 min was obtained from pressurized technique (screw press) briquettes and shortest (3 min) from those made from non-pressurized (Table 1). Results from these studies are much higher than what was observed from individual feedstocks. For instance, Ikelle et al. [16] reported an ignition time of 27.20 sec for corncobs while rice husks had a value of 23.33 sec. Oyelaran, O. A. [38] reported a value of 96 sec for ignition time of briquettes made from sugarcane bagasse. For the two feedstocks, Ikelle et al. [16] recorded higher values than those of individual feedstocks for corncobs and rice husks blended with coal as 56.14 and 41 sec respectively. Kabok et al. [18] reported ignition time of 2.7 min in a study where fecal sludge and sawdust were utilized as feedstocks. Values in this study compares well with 3 min and 3-4 min reported by Ndindeng et al. [29] and Anggraeni et al. [6] respectively who used three feedstocks in briquetting. A lower value (2.1 min) was reported Abdulkareem et al. [1] for briquettes made of charcoal, sawdust and sugarcane bagasse by use of a hydraulic compression machine. However, values from this study were slightly lower than 6-11 min reported Kizito et al. [21] from briquettes of dried fecal sludge blended with food market waste.

Ignition time increased with an increase in number of feedstocks and increased pressure. According to Davies, R. [12] highly compressed biomass or an increase in compaction reduces the void spaces of briquettes as particles are forced closer hence causing elongation of the ignition time. Abdulrasheed et al. [2] reported that briquettes with low compaction have low density (high porosity) and thus, ignite and burns faster. These explain why briquettes made using screw press had longest ignition time (Table 1). Demirbas, A. [14] though recommend that briquettes for domestic use should be easily ignitable.

3.1.2. Time to Boil

Time to boil water (minutes), which is the average time taken for the briquettes to bring water to the boiling point, was longest (14 min) with the pressurized technique (screw press). Shortest time to boil, 12 and 11 min was from low pressurized techniques used. Time reduced from cold start to hot start (Table 1) since briquettes were still hot from cold start phase. Time to boil for individual feedstocks was higher since values of 16 and 16.17 min were reported for corncobs and rice husks briquettes respectively [16]. Song, B. [41] reported 15 min and 10 min for charred corncobs and sawdust briquettes respectively. 18–26 min was recorded by Kabok et al. [18] for carbonized FS-sawdust briquettes. 17.48 and 16.43 min were reported by Ikelle et al. [16] when rice husks and corncobs respectively were blended with coal. Abdulkareem et al. [1] used dial gauge hydraulic compression machine to produce briquettes from three feedstocks of charcoal, sawdust and sugarcane bagasse and recorded a lower value of 5.1-7.3 minutes. Onuegbu et al. [36] while using (manually operated hydraulic press – high pressurized) to produce briquettes from three feedstocks reported a value of 8-26 min.

It can therefore be concluded that number of feedstocks used in briquetting has no effect on time to boil. However, technique used has significant effect due to pressure involved. Increase in density due to pressurized techniques inhibits percolation of oxygen into the fuel thus briquettes from screw press had the longest time to boil. Lubwama, M. [25] reported that time to boil is attributed to quantity of fuel and the type of cooking stove.

3.1.3. Burning Rate

The burning rate, (g/min), was taken as the ratio of the mass of fuel burnt to the total time taken in line with Kizito et al. [21]. Pressurized technique (screw press) briquettes gave the least value of 0.8 g/min while highest values were obtained from non-pressurized techniques with values of 1.1 and 1.3 g/min for drum agglomerator and hand briquetting respectively. High burning rates in briquettes implies that more briquettes will be required in combustion as they burn off readily as reported by Onukak et al. [37]. Sunnu et al. [42] reported higher values for individual feedstocks of 4.28-5.44, 5.98-6.33, 6.20-6.35 and 10.06-10.43 g/min for charred palm kernel shell, corncobs, rice husks and sawdust respectively with a pressurized technique (manual hydraulic press). Two feedstocks (rice husks and cassava peels) were used with a high-pressure technique by Anggraeni et al. [6] and reported a value of 2.81 g/min which was higher than three feedstocks but lower than value obtained from single feedstock.

Compared to other briquettes in literature, the burning rates in this study compares well with (1.1-2.1 g/min) range reported by Ndindeng et al. [29] from three feedstocks using locally fabricated multi-piston press. Also, Davies, R. M. [13] reported a similar value of (0.97-2.49 g/min) from three feedstocks when a non-pressurized technique was used to produce briquettes. The values in the study were lower than 2.85 g/min reported by Bonsu et al. [8] based on a non-pressurized technique (compressor box) from kernel shells briquettes but higher than 0.4-0.5 g/min from three feedstocks of charcoal, sawdust, and sugarcane bagasse reported by Abdulkareem et al. [1] who used hydraulic compression machine. The 0.44–0.53 g/min obtained from coconut shell blended with charcoal dust briquettes Kongprasert et al. [22] were also lower.

Navalta et al. [28] reported that burning rate of briquettes depends on biomass type and density. Burning rate was therefore significantly affected by number of feedstocks and technique used to produce briquettes. In this study, the low burning rate in screw press is attributed to the high density of the briquettes from pressurized technique. The effect of technique on briquettes burning rate is shown in Figure 1.

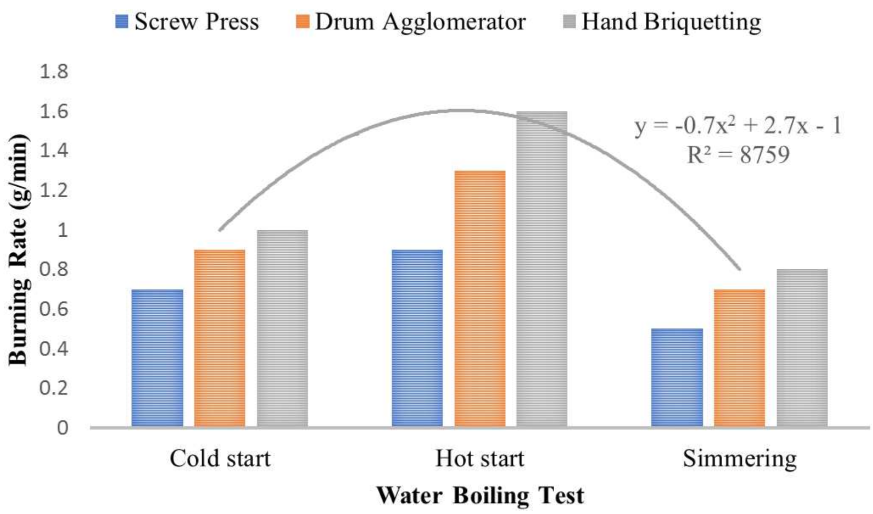

Figure 1. *Effect of briquetting technologies on burning rate.*

The graph obtained in Figure 1 has an R^2=87.59%. Short bars represent briquettes from screw press which indicate that low amount of fuel was needed to bring water to boil for a pressurized technique.

3.1.4. Specific Fuel Consumption (g/ml)

Specific fuel consumption (SFC), in g/ml, was taken as the amount of fuel needed to bring a certain quantity of water to boiling point and was 0.11 for the pressurized technique while low pressure techniques gave values of 0.13 and 0.15 for drum agglomerator and handmade briquettes respectively. More consumption of fuel was in cold start due to heat required for warming the cook stove and the surrounding as in Table 1. Considering single feedstock, a study by Sunnu et al. [42] reported higher values of 2.38-2.75, 3.82-4.11 and 4.52-4.65 kg/l for sawdust, rice husks and corncobs respectively. Lower values (0.41-0.56 g/ml) than what was observed from individual feedstocks was reported by Anggraeni et al. [6] from two feedstocks (rice husks and cassava peels) using high pressurized technique.

Values in the study are close to the range (0.14- 0.17 Kg/L) reported by Kpalo et al. [23] while using hydraulic piston press with three feedstocks. Abdulrasheed et al. [2] though used pressurized technique and recorded a higher value of (0.29- 0.34 Kg/L) with three feedstocks. Mbuba et al. [27] reported density to be a factor affecting specific fuel consumption which explains why screw press had low value. SFC was therefore significantly affected by both number of feedstocks and technique used to produce briquettes. The values decreased with an increase in number of feedstock and applied pressure. Effect of technique on briquettes SFC is shown in Figure 2.

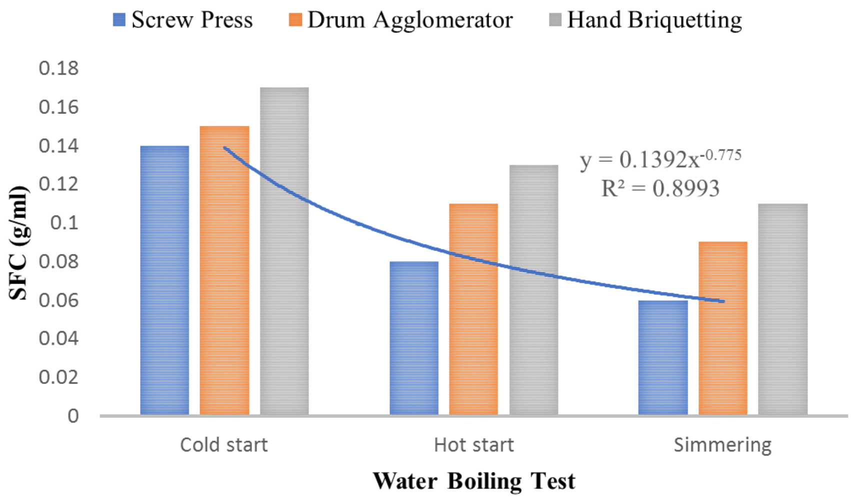

Figure 2. *Effect of briquetting technology on specific fuel consumption.*

The graph in Figure 2 has an R^2=89.9%. Short bars represent fuel from screw press technique; hence, low amount of fuel was needed for briquettes from pressurized technique to bring water to boil.

3.1.5. Power Output (kW)

Power output (kW) was taken as the amount of energy released from the fuel in a given time in line with [38] and was 1.8, 1.4 and 0.75 for screw press, drum agglomerator and hand briquetting respectively (Table 1). Power output increased in high power phase and decreased during simmering; that is, pyrolysis was already complete and less producer gas was available for combustion. The values (1.4-1.56 kW) obtained from a study by Sawadogo et al. [46] using single feedstock of fruits bunches of oil palm plant and (1.3-1.5 KW) by [39] using cashew industry waste compares well to this study using non-pressurized and pressurized techniques respectively. The values for this study are slightly higher than 0.39 kW reported by Nwabue et al. [32] for two feedstocks of bio coal with plastic waste using hydraulic jack as the technique. A higher value of 4.18- 4.46 kW was reported from hydraulic powered press that produced briquettes from sawdust (one feedstock) with Styrofoam adhesive as binder Abdulrasheed et al. [2].

Power output was not significantly affected by number of feedstocks used rather type of biomass. However, technique used to produce briquettes was a factor depending on applied pressure. This is why highly compressed briquettes from pressurized technique (screw press) took more time to burn and hence less amount was consumed to bring water to the boil. Effect of technique on briquettes power output is shown in Figure 3.

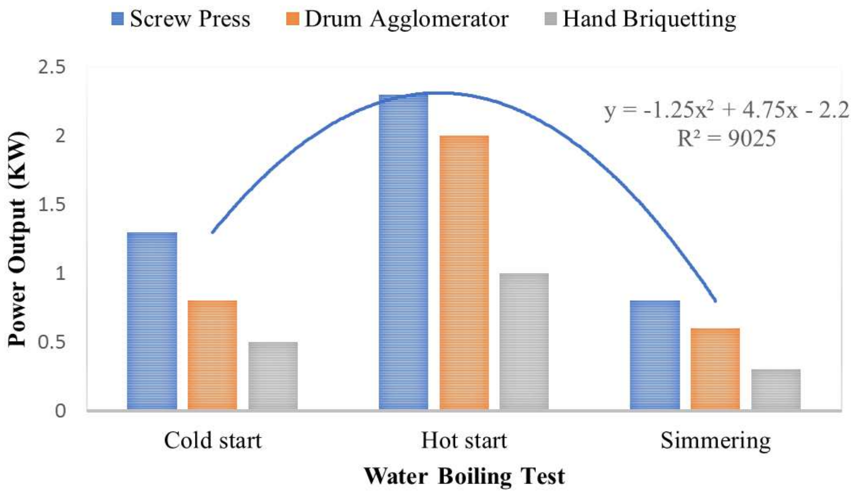

Figure 3. *Effect of technique on briquettes power output.*

The graph (Figure 3) has an R^2=90.25%. The tall bars from Water Boiling Test represents pressurized technique (screw press) and indicate high power output was gotten from the fuel while non-pressurized techniques are represented by short bars.

3.2. ANOVA for Briquetting Techniques and Performances Properties

Table 2 shows the results of the one-way ANOVA for parameters of briquettes derived from rice husks, corncobs and sugarcane bagasse. The mean values for briquettes performance properties were all significantly different ($p < 0.05$) among the different techniques.

ANOVA showed significant difference ($p < 0.05$) on ignition and time to boil between pressurized and non-pressurized techniques since p values (0.02/0.04) were less than 0.05. However, there was no significant difference between drum agglomerator and handmade (both are low pressure techniques) as in Table 2, though, briquettes from drum agglomerator took slightly longer time than handmade to boil water. ANOVA showed that there was a significant difference in burning rate and specific fuel consumption of briquettes among the three techniques since p values (0.01) were less than 0.05 (Table 2). The power output was significantly different among the briquettes from the three techniques with a p value of 0.001.

Table 2. *ANOVA for Briquettes Performances Properties from different Techniques.*

TECHNOLOGIES	Ignition Time (Min)	Time to Boil (Min)	PARAMETERS	S.F.C* (g/ml)	Power Output (KW)
			Burning Rate (g/min)		
Screw Press Machine	1.3^{a}	14^{a}	0.8^{a}	0.11^{a}	1.8^{a}
Drum Agglomerator	1.0^{b}	12^{b}	1.1^{b}	0.13^{b}	1.4^{b}
Hand Made	0.9^{b}	11^{b}	1.3^{c}	0.15^{c}	0.75^{c}
Std Error of Mean	0.07	0.38	0.35	0.84	0.13
P value	<0.02	<0.04	<0.01	<0.01	<0.001

*S.F.C=specific fuel consumption

Means within a column with the different superscript letters across column are statistically different $p > 0.05$.

4. Conclusions

Briquetting techniques and number of feedstocks are factors that influence performance characteristics of briquettes. Increase in number of feedstocks raised ignition time. Also, ignition time varied depending on technique used as pressurized technique (Screw press) registered high value. Also, burning rate and specific fuel consumption were significantly influenced by number of feedstocks and technique used. An increase in number of feedstocks or pressure resulted in corresponding decrease in performance values. However, time to boil and power output were not affected by number of feedstocks but rather technique used during production. Pressurized technique produced higher density briquettes that led to an increase in time to boil and power output. Diversified power sources technique could hence be used to convert the agricultural and or other wastes to useful energy products for domestic application. From the study, a recommendation for future research is advised on a four-mix ratio to be undertaken to ascertain findings of this study.

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References

[1] Abdulkareem, S., Hakeem, B. A., Ahmed, I. I., Ajiboye, T. K., Adebisi, J. A., & Yahaya, T. (2018). *Combustion Characteristics of Bio-Degradable Biomass Briquettes*. *13*, 13.

[2] Abdulrasheed, A., Aroko, U. O., & Ibrahim, M. (2015). *Compression Pressure Effect on Mechanical & Combustion Properties of Sawdust Briquette using Styrofoam adhesive as binder*. 15, 7.

[3] Adeleke, A. A., Ikubanni, P. P., Orhadahwe, T. A., Christopher, C. T., Akano, J. M., Agboola, O. O., Adegoke, S. O., Balogun, A. O., & Ibikunle, R. A. (2021). Sustainability of multifaceted usage of biomass: A review. *Heliyon*, *7* (9), e08025. https://doi.org/10.1016/j.heliyon.2021.e08025.

[4] Adeniyi, A. G., & Ighalo, J. O. (2020). Computer-Aided Modeling of Thermochemical Conversion Processes for Environmental Waste Management. In C. M. Hussain (Ed.), *Handbook of Environmental Materials Management* (pp. 1–16). Springer International Publishing. https://doi.org/10.1007/978-3-319-58538-3_185-1.

[5] Ajimotokan, H. A., Ehindero, A. O., Ajao, K. S., Adeleke, A. A., Ikubanni, P. P., & Shuaib-Babata, Y. L. (2019). Combustion characteristics of fuel briquettes made from charcoal particles and sawdust agglomerates. *Scientific African*, *6*, e00202. https://doi.org/10.1016/j.sciaf.2019.e00202.

[6] Anggraeni, S., Hofifah, S. N., & Nandiyanto, A. B. D. (2021). *Effects of Particle Size and Composition of Cassava Peels and Rice Husk on The Briquette Performance*. *16*, 16.

[7] Berrueta, V. M., Edwards, R. D., & Masera, O. R. (2008). Energy performance of wood-burning cookstoves in Michoacan, Mexico. *Renewable Energy*, *33* (5), 859–870. https://doi.org/10.1016/j.renene.2007.04.016.

[8] Bonsu, B. O., Takase, M., & Mantey, J. (2020). Preparation of charcoal briquette from palm kernel shells: case study in Ghana. Heliyon 6, e05266. https://doi.org/10.1016/j.heliyon.2020.e05266.

[9] Cardil, A., de-Miguel, S., Silva, C. A., Reich, P. B., Calkin, D., Brancalion, P. H. S., Vibrans, A. C., Gamarra, J. G. P., Zhou, M., Pijanowski, B. C., Hui, C., Crowther, T. W., Hérault, B., Piotto, D., Salas-Eljatib, C., Broadbent, E. N., Almeyda Zambrano, A. M., Picard, N., Aragão, L. E. O. C., & Liang, J. (2020). Recent deforestation drove the spike in Amazonian fires. *Environmental Research Letters*, *15* (12), 121003. https://doi.org/10.1088/1748-9326/abcac7.

[10] Chirchir, D. K., Nyaanga, D. M., & Githeko, J. M. (2013). *Effect of Binder Types and Amount on Physical and Combustion Characteristics*. 11.

[11] da Silva, S. B., Arantes, M. D. C., de Andrade, J. K. B., Andrade, C. R., Carneiro, A. de C. O., & Protásio, T. de P. (2020). Influence of physical and chemical compositions on the properties and energy use of lignocellulosic biomass pellets in Brazil. *Renewable Energy*, *147*, 1870–1879. https://doi.org/10.1016/j.renene.2019.09.131.

[12] Davies, R., & Abolude, D. (2013). Ignition and Burning Rate of Water Hyacinth Briquettes. J. Sci. Res. Rep. 2, 111–120. https://doi.org/10.9734/jsrr/2013/1964.

[13] Davies, R. M., & Davies, O. A. (2013). Physical and Combustion Characteristics of Briquettes Made from Water Hyacinth and Phytoplankton Scum as Binder. *Journal of Combustion*, *2013*, 1–7. https://doi.org/10.1155/2013/549894.

[14] Demirbas, A., & Sahin-Demirbas, A. (2004). Briquetting Properties of Biomass Waste Materials. *Energy Sources*, *26* (1), 83–91. https://doi.org/10.1080/00908310490251918.

[15] Grover P., & Mishra K (2006), "Development of an Appropriate Biomass Briquetting Technology Suitable for Production and Use in Developing Countries", *Biomass Conversion Technology Journal,* Vol. 1, p. 45-48.

[16] Ikelle, I. I., Anyigor, C and Ogah, S. P. (2018). The Characterization of the Heating Properties of Briquettes of Coal and Rice Husk, IOSR Journal of Applied Chemistry (IOSR-JAC), e-ISSN: 2278-5736. Volume 7, Issue 5 Ver. II, pp. 100-105.

[17] Jamradloedluk, J., & Wiriyaumpaiwong, S. (2007). Production and Characterization of Rice Husk Based Charcoal Briquettes, *KKU Engineering Journal, vol. 34 (4),* 391-398.

[18] Kabok, P., Nyaanga, D. M., Mbugua, J. M., & Eppinga, R. (2018). Effect of Shapes, Binders and Densities of Faecal Matter - Sawdust Briquettes on Ignition and Burning Times. J. Pet. Environ. Biotechnol. 09 https://doi.org/10.4172/2157-7463.1000370.

[19] Kaur, S., Kumar, D., Singla, M., & Dogra, R. (2020). Biogas to Bio-CNG from paddy straw: A review. *International Journal of Chemical Studies*, *8* (3), 1833–1838. https://doi.org/10.22271/chemi.2020.v8.i3y.9475.

[20] Kaur, A.; Roy, M. and Kundu, K. (2017). Densification of Biomass by Briquetting: *A Review. Int. J. Recent Sci. Res.* 8, 20561–20568.

[21] Kizito, S., Jjagwe, J., Ssewaya, B., Nekesa, L., Tumutegyereize, P., Zziwa, A., & Komakech, A. J. (2021). Biofuel characteristics of non-charred briquettes from dried fecal sludge blended with food market waste: Suggesting a waste-to-biofuel enterprise as a win–win strategy to solve energy and sanitation problems in slums settlements. *Waste Management*, S0956053X21006176. https://doi.org/10.1016/j.wasman.2021.11.029.

[22] Kongprasert, N., Wangphanich, P., & Jutilarptavorn, A. (2019). Charcoal briquettes from Madan wood waste as an alternative energy in Thailand. Procedia Manuf. 30, 128–135. https://doi.org/10.1016/j.promfg.2019.02.019.

[23] Kpalo, S. Y., Zainuddin, M. F., Manaf, L. A., & Roslan, A. M. (2020b). A Review of Technical and Economic Aspects of Biomass Briquetting. *Sustainability*, *12* (11), 4609. https://doi.org/10.3390/su12114609.

[24] Kumar, R., Strezov, V., Weldekidan, H., He, J., Singh, S., Kan, T., & Dastjerdi, B. (2020). Lignocellulose biomass pyrolysis for bio-oil production: A review of biomass pre-treatment methods for production of drop-in fuels. *Renewable and Sustainable Energy Reviews*, *123*, 109763. https://doi.org/10.1016/j.rser.2020.109763.

[25] Lubwama, M., & Yiga, V. A. (2018). Characteristics of briquettes developed from rice and coffee husks for domestic cooking applications in Uganda. Renew. Energy 118, 43–55. https://doi.org/10.1016/j.renene.2017.11.003.

[26] Lubwama, M., Yiga, V. A., Muhairwe, F., & Kihedu, J. (2019). Physical and combustion properties of agricultural residue bio-char bio-composite briquettes as sustainable domestic energy sources. Renew. Energy. https://doi.org/10.1016/j. renene.2019.10.085.

[27] Mbuba, J., Nyaanga, D. M., Kabok, P., & Eppinga, R. (2017). Effect of mix ratios and binders on physical and physical combustion characteristics of faecal matter-sawdust briquettes. Int. J. Emerg. Technol. Adv. Eng. 7, 94–99.

[28] Navalta, C. J. L. G., Banaag, K. G. C., Raboy, V. A. O., Go, A. W., Cabatingan, L. K., & Ju, Y.-H. (2020). Solid fuel from Co-briquetting of sugarcane bagasse and rice bran. *Renewable Energy*, *147*, 1941–1958. https://doi.org/10.1016/j.renene.2019.09.129.

[29] Ndindeng, S. A., Mbassi, J. E. G., Mbacham, W. F., Manful, J., Graham-Acquaah, S., Moreira, J., Dossou, J., & Futakuchi, K. (2015). Quality optimization in briquettes made from rice milling by-products. *Energy for Sustainable Development*, *29*, 24–31. https://doi.org/10.1016/j.esd.2015.09.003.

[30] Nguyen, Q. A., Smith, W. A., Wahlen, B. D., & Wendt, L. M. (2020). Total and Sustainable Utilization of Biomass Resources: A Perspective. *Frontiers in Bioengineering and Biotechnology*, *8*, 546. https://doi.org/10.3389/fbioe.2020.00546.

[31] Nunes, L. J. R., Causer, T. P., & Ciolkosz, D. (2020). Biomass for energy: A review on supply chain management models. *Renewable and Sustainable Energy Reviews*, *120*, 109658. https://doi.org/10.1016/j.rser.2019.109658.

[32] Nwabue, F. I., Unah, U., & Itumoh, E. J. (2017). Production and characterization of smokeless bio-coal briquettes incorporating plastic waste materials. *Environmental Technology & Innovation*, *8*, 233–245. https://doi.org/10.1016/j.eti.2017.02.008.

[33] Ochola, G. O. (2018). Urbanization and Environmental Stress: A Review of Impacts of Urban Development on the Environment in Kenya. *International Journal of Environmental Sciences & Natural Resources*, *14* (3). https://doi.org/10.19080/IJESNR.2018.14.555889.

[34] Olorunnisola, A. (2004). Briquetting of rattan furniture waste. *Journal of Bamboo and Rattan,* 3 (2), 139-149.

[35] Onaji P. B., & Siemons R. V. (2003). "Production of Charcoal Briquettes from Cotton Stalks in Malawi: Methodology for Feasibility Studies using Experiences in Sudan." *Biomass and Bioenergy*, 4: 199-211.

[36] Onuegbu, T. U., Ekpunobi, U. E., Ogbu, I. M., Ekeoma, M. O., & Obumselu, F. O. (2011). Comparative studies of ignition time and water boiling test of coal and biomass briquettes blend. Int. J. Res. Rev. Appl. Sci. 7, 153–159.

[37] Onukak, I. E., Mohammed-Dabo, I. A., Ameh, A. O., Okoduwa, S. I. R., & Fasanya, O. O. (2017). Production and characterization of biomass briquettes from tannery solid waste. Recycling 2. https://doi.org/10.3390/recycling2040017.

[38] Oyelaran, O. A. (2015). *Evaluating the bio-energy potential of groundnut shell and sugarcane bagasse waste composite*. 5.

[39] Sawadogo, M., Tchini Tanoh, S., Sidib´e, S., Kpai, N., & Tankoano, I. (2018). Cleaner production in Burkina Faso: Case study of fuel briquettes made from cashew industry waste. J. Clean. Prod. 195, 1047–1056. https://doi.org/10.1016/j. jclepro.2018.05.261.

[40] Sharma, D., Ravindra, K., Kaur, M., Prinja, S., & Mor, S. (2020). Cost evaluation of different household fuels and identification of the barriers for the choice of clean cooking fuels in India. *Sustainable Cities and Society*, *52*, 101825. https://doi.org/10.1016/j.scs.2019.101825.

[41] Song, B., & Hall, P. (2020). Densification of Biomass and Waste Plastic Blends as a Solid Fuel: Hazards, Advantages, and Perspectives. *Frontiers in Energy Research*, *8*, 58. https://doi.org/10.3389/fenrg.2020.00058.

[42] Sunnu, A. K., Adu-Poku, K. A., & Ayetor, G. K. (2021). Production and Characterization of Charred Briquettes from Various Agricultural Waste. *Combustion Science and Technology*, 1–22. https://doi.org/10.1080/00102202.2021.1977803.

[43] Trigueiro, W. R., Nabout, J. C., & Tessarolo, G. (2020). Uncovering the spatial variability of recent deforestation drivers in the Brazilian Cerrado. *Journal of Environmental Management*, *275*, 111243. https://doi.org/10.1016/j.jenvman.2020.111243.

[44] Tumuluru, J. S., & Fillerup, E. (2020). Briquetting characteristics of woody and herbaceous biomass blends: Impact on physical properties, chemical composition, and calorific value. *Biofuels, Bioproducts and Biorefining*, *14* (5), 1105–1124. https://doi.org/10.1002/bbb.2121.

[45] Tumuluru, S. J.; Wright, C. T.; Hess, J. R., & Kenney, K. L. (2011). A review of biomass densification systems to develop uniform feedstock commodities for bioenergy application. *BiofuelsBioprod. Bioref.* 5, 683–707.

[46] Ugwu, K. & Agbo., K. (2013). Evaluation of Binders in the Production of Briquettes from Empty Fruit Bunches of Elais Guinensis. *International Journal of Renewable and Sustainable Energy*, *2* (4), 176. https://doi.org/10.11648/j.ijrse.20130204.17.

[47] Wilaipon, P. (2009). *The Effects of Briquetting Pressure on Banana-Peel Briquette and the Banana Waste in Northern Thailand*. 5.